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A holistic overview of the progress of China's low-carbon city pilots

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ABSTRACT

Since 2010 China has launched three batches of low-carbon pilot cities to explore feasible local policies or actions that can be replicated on a larger scale. Based on their official self-assessment reports, this study investigates the progress of 32 pilot sites from the initial two batches. Indicators of progress include: establishing a comprehensive governance system to guarantee the implementation of low-carbon strategies, plans and actions; implementing a carbon emission statistics system; carrying out low-carbon actions covering the majority of emission sectors and having produced positive consequences for local low-carbon development; exploring new policies and institutions including legislation, emissions control, carbon certification and green credit schemes, that lead to the formulation of national policies. Despite some defects in the experiments, the progress from these pilot sites has laid an important foundation for the advancement of national low-carbon development. Based on this analysis, this study provides recommendations for policy diffusion: to integrate more constraints and incentives into low-carbon pilot sites; to establish a policy assessment system to identify effective local experiments; and to summarize and share these best practices across the country.

1. Introduction

1.1. Facilitating national emissions reduction through low-carbon cities

Climate change caused by increasing greenhouse gas (GHG) emissions is one of the biggest challenges facing the world. To mitigate climate change, a series of international agreements have set explicit targets for reducing GHG emissions. For example, the Copenhagen Accord adopted in 2009 set a long-term goal of "holding global warming to well below 2 °C compared to pre-industrial levels", and the Paris Agreement adopted in 2015 emphasized the target and planned to further pursue efforts to limit warming to 1.5 °C" (UNFCCC, 2015). In response to international efforts to mitigate climate change, many countries have set targets to reduce carbon emissions. China, the biggest national emitter, with emission reaching 28.2% of the world total in 2014 (IEA, 2014), has initiated a two-step strategy to control its emissions. First, by 2020, its CO_2 emissions intensity will be reduced 40–45% compared to the 2005 level. Second, by around 2030 or earlier, its total emissions will peak.

To achieve the carbon emission reduction targets, the country has focused on reducing energy intensity, improving its share of renewable energy, increasing forest stock volume and set binding targets in three consecutive Five Year Plans (FYP): the 11th, 12th and 13th FYPs, from 2005 to 2020. Currently, the targets of the 11th and 12th FYPs have been achieved. Although emissions intensity has decreased continually, China's CO_2 emissions have still been dominated by rapid GDP growth (Peters, Weber, Guan, & Hubacek, 2007). From 2005 to 2015, China's carbon intensity decreased by 37%, while total emissions increased by about 57% (Qi, 2017). Given rapid urbanization and industrialization, citizens have transitioned into more energy-intensive lifestyles, which may make the growth of the economy and greenhouse gas emissions tightly coupled in the future (Moriarty & Wang, 2014; Qi, 2013). Reducing CO_2 intensity per GDP and achieving the emission peak earlier than expected have thus been an urgent challenge for both the central and local governments (Wang & Chang, 2014).

As significant contributors to CO_2 emissions, cities are natural stakeholders in all climate mitigation efforts (Baeumler et al., 2012; Lee & Erickson, 2017). Worldwide, building low carbon cities has become a core strategy to address climate change, and more and more cities have established low-carbon development as an objective and taken corresponding actions under their city's development blueprint (Tan et al., 2017). Meanwhile, several transnational cities' networks engaged in

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climate change have also developed. For examples, the C40 Cities Climate Leadership Group, a network of the world's megacities taking action to reduce GHG emissions, has involved 96 cities (C40, 2018). The Covenant of Mayors, launched in 2008 by the European Commission to endorse and support the efforts of local authorities in the implementation of climate change mitigation policies, has involved 7755 signatories, and 6038 signatories have submitted their action plans (The Covenant of Mayors, 2018). In China, the concept of a low-carbon city has become more prevalent since 2008, when Shanghai and Baoding joined the low-carbon city initiative sponsored by the World Wildlife Fund (Wang & Chang, 2014). In 2010, the National Development and Reform Commission (NDRC) - China's top agency responsible for formulating and implementing national climate strategies - initiated a national low carbon pilot program, encompassing five provinces and eight cities. In 2012, the NDRC expanded its low-carbon pilot sites to 6 provinces and 36 cities. From that more and more cities have integrated low-carbon targets into their city planning. According to an investigation by the China City Association, 133 of 287 cities sampled had raised their low-carbon targets by 2012 (The Chinese Society for Urban Studies, 2013). In 2014, the National Plan of New Urbanization issued by the State Council established the principle of future urbanization as "intensive, smart, green, and low-carbon". Developing low-carbon cities has since become China's national strategy. In 2016, the NDRC announced the 3rd batch of low-carbon pilots. Currently, the low-carbon pilots have involved in 6 provinces, 4 provincial-level municipalities, 69 prefecture-level cities, 4 county-level cities, 3 countries and 1 district (Fig. 1).

1.2. Current research on low-carbon cities in China

With the implementation of the low-carbon develop strategy, the awareness and popularity of the low-carbon city has increased significantly in recent years, and the amount of scholarly work has increased immensely (Cai et al., 2017; Liu & Qin, 2016; Wang, Engels, & Wang, 2018). At the city level, current research mainly focuses on two core topics: What is a low carbon city, and what policies can develop a low-carbon city?

There is no universal, literal definition of a low-carbon city in the existing literature; however, we could summarise consensus points by concluding that a low-carbon city is one comprised of three main dimensions. Firstly, a low-carbon city can be regarded as the executive location of both a low-carbon economy and a low-carbon society, and its core goal is to reduce GHG emissions (Cheng, Zeng, & Fang, 2012). Secondly, the low-carbon idea should penetrate into all fields of urban development, including production, consumption and governance (Baeumler et al., 2012; Cheshmehzangi, Xie, & Tan-Mullins, 2018; Su et al., 2016; Yang & Li, 2013). Usually, a low-carbon city includes five sectors as the main pillars of its transition strategy, namely: 'Energy', 'Buildings', 'Transportation', 'Industrial' and 'others'. Thirdly, although studies have developed various index systems to measure and evaluate a city's low-carbon level (Tan, Yang, & Yan, 2015, 2017; Wang & Chi, 2016), most policymakers refer to low-carbon cities as "transition experiments" (Hu, 2017; Williams, 2016). In practice, a low-carbon city strategy focuses on how cities change their GHG emission trajectories independent of their initial carbon endowments, but in ways that do not compromise economic development and livability (Baeumler et al., 2012).

According to current studies (Baeumler et al., 2012; Wang et al., 2018; Yang & Li, 2013), developing a low-carbon city involves four key steps. Firstly, it is important to know the city's carbon footprint by compiling a GHG emissions inventory and identifying the factors influencing GHG emissions. Secondly, it is necessary to establish a GHG

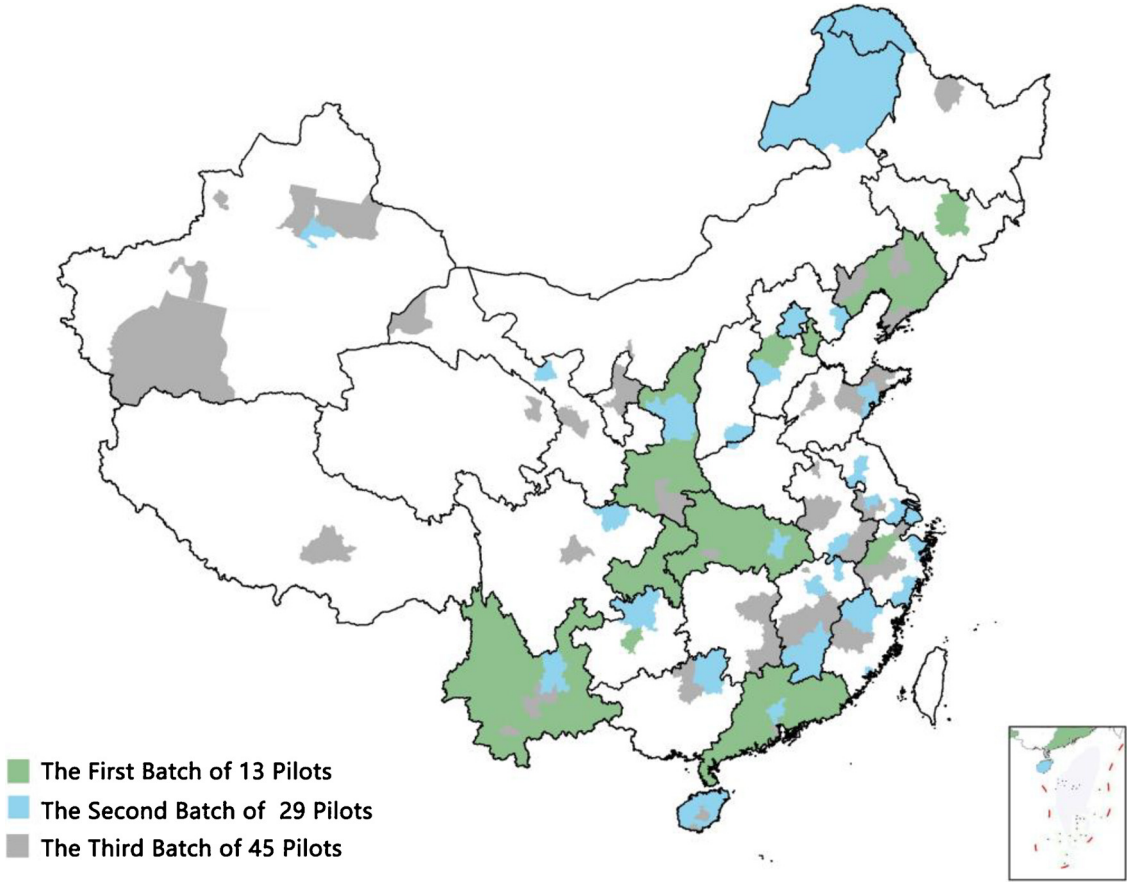

Fig. 1. Geographical distribution of the three batches of low-carbon pilots.

reduction goal based on abatement potential and costs. Thirdly, one should design and implement a low-carbon city action plan. Last but not least, there needs to be measures of progress by evaluation indicator systems. Focusing on some key issues of how to develop a low-carbon city, current studies have offered some applicable methods to account for city-level CO_2 emissions inventories (Bi, Zhang, Wang, Liu, & Wu, 2011; Fry et al., 2018; Sugar, Kennedy, & Leman, 2012), to identify key factors influencing CO_2 emissions (Chong, Guan, & Guthrie, 2012; Fang, Wang, & Li, 2015; Wang & Liu, 2017; Wang et al., 2014), to explore paths to building low-carbon cities (Moriarty & Wang, 2014; Tao, 2011; Zhang, Feng, & Chen, 2011), and to develop evaluation indicator systems of low-carbon cities (Lin, Jacoby, Cui, Liu, & Lin, 2014; Tan et al., 2017; Wang & Chi, 2016; Zhou, He, Williams, & Fridley, 2015). The existing literature outlines some key profiles of a low-carbon city, but few articles have presented a holistic solution for establishing a low-carbon city.

Current studies also pay attention to China's low-carbon city pilots. Yang and Li (2013) investigated the progress of 8 pilot low-carbon cities in the first batch and pointed out several deficiencies of China's pilot project, including: lack of explicit definition for low-carbon city and insufficient supporting policies. Wang, Song, He, and Qi, (2015) illustrated the status-quos of 36 low-carbon cities in the initial two batches and found that innovative policies have been widely applied in the form of command-mandatory tools, market-economic tools and voluntary tools. Su et al. (2016) conducted a brief overview of China's low-carbon pilots and summarized the measures applied by pilots from the perspectives of planning, energy system, ecological industry, green transportation and green building. Liu and Qin (2016) provided a systematic review on China's low-carbon city policies and found that China has largely formed a multi-layer and multi-actor policy-making process for developing low-carbon cities. Such studies are helpful in understanding China's low-carbon city practices, but several topics still need to be researched further, including: how low-carbon development goals are actually implemented in China's low-carbon city pilot projects, and the role of governments and the issues of governance during the construction of low-carbon cities (Wang et al., 2018).

1.3. Objectives of this study

In this study, we analyze the self-assessment reports of the 32 prefectural city pilots in the initial two batches in order to examine the progress of China's low-carbon pilot project. We analyze this progress from two profiles. At the national level, we analyze the evolution of China's low-carbon city pilot policies. At the city level, we analyze how national low-carbon goals are actually implemented in China's low-carbon city pilot projects. Compared with the existing literature, this study exclusively focuses on the actual implementation of China's official low-carbon pilots. A large body of existing studies attempts to show how to develop a low-carbon city, while this study outlines the actual experiences of China's 32 low-carbon pilot cities.

To present a holistic picture of progress in China's low-carbon pilots, the rest of this article will be arranged as follows. The second section describes the research framework and methodology, setting up the preparation for our analysis. The third section illustrates the evolution of China's low-carbon pilot policies. The fourth section summarizes the progress of 32 national pilots in performance, governance system, carbon emissions statistical system, sectoral actions and policy explorations. The fifth section discusses obstacles to the spread of local experiments across the whole country. The sixth section offers a conclusion and policy recommendations.

2. Methodology

2.1. Analytical framework

In China's centralized government system, a pilot is one of the most important forms of policy, which is considered a key factor in China's economic rise (Heilmann, 2008). Its policy process is a combination of "bottom-up" and "top-down". In the pilot programs, the central government attempts to collect local practical experiences and identify appropriate strategies and tactics that can be applied to the whole country, while the local governments expect to obtain more support from the central government and get advantages in regional competition. Therefore, the progress of a pilot project can be summarized from two profiles: the national requirements and cities' responses.

Establishing low-carbon pilots is a process incorporating the central government's mobilization and local governments' spontaneity. The process can be generalized as three stages: the NDRC releases an application notice to mobilize the local governments to apply, and then active local governments submit their applications to the NDRC, and finally the NDRC establishes the final pilot lists based on its own criteria and tasks. The NDRC also offers specific supports for these pilots, including offering research funds and technology assistance, conducting capability training and promoting international collaboration. In this study, we summarize national requirements for city pilots into three elements: criteria, tasks and supporting policy.

Since policy pilots are a purposeful activity, the tasks approved by the NDRC are the crucial reference for summarizing local progress. Combining these tasks and the steps of how to develop a low-carbon city, we summarize cities' response to national requirements into five further elements: governance systems, goals, carbon emissions statistical system, sectoral practice, and policy and institutional exploration.

The national requirements and cities' responses outline the working mechanism of a pilot project. In order to compare China's pilot project with other international low-carbon city networks, we summarize the working mechanism with three key questions: How to join the network? How to facilitate the cities' conducting of climate actions? How to collect, evaluate and diffuse the local experiments?

2.2. Scope

Although the NDRC established three batches of pilots, the 3rd batch of pilots just began. To explore the realistic progress of China's low-carbon pilots, this study focuses on the initial two batches, which were implemented in 2010 and 2012, respectively. In addition, according to administrative levels, Chinese cities are divided into three groups: provincial-level municipalities, prefecture-level cities and county-level cities, which correspond to the first three levels of China's five administrative hierarchies of province, prefecture, country, town and village. Owing to the differences in administrative power, it is not convenient to compare among the different level cities. As a result, this study chooses 32 prefectural-pilots in the initial two batches to examine the progress of the low-carbon city pilot project.

The 32 cities cover 25 provinces. In 2015, their GDP, population, energy consumption and emissions related to energy accounted for 22.8%, 13.0%, 16.1% and 15.8% of the country's total amounts, respectively (Fig. 2).

From the perspective of carbon emissions per capita, 20 of the 32 pilots were higher than the national average (6.77tCO_2/p) in 2015 (see Fig. 3). The highest city was Jiyuan, whose emissions per capita reached 19.31tCO_2, 2.85-times the national average. Jiyuan is followed by Urumchi and Jinchang. Compared to GDP per capita, the three cities show an astonishingly high emission per capita, because their industries were dominated by energy intensive industries such as electric power, iron and steel and non-ferrous metals. The lowest city was Ganzhou, whose emission per capita was only 1.74tCO_2, less than one quarter of the national average. Considering GDP per capita, 24 of the 32 pilots were higher than the national average (49,229 Yuan/p, equivalent to 7459 Dollars/p) in 2014 (see Fig. 3). The highest city was Suzhou, whose GDP per capita reached 136,899 Yuan (about 20,742 Dollars), 2.78-times the national average; while the lowest three pilots – Ganzhou, Guangyuan and Great Khingan, whose GDP per capita levels

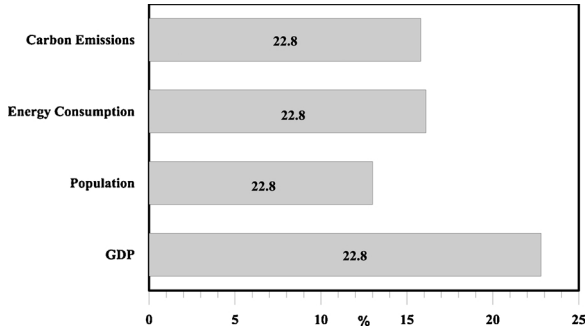

Fig. 2. The pilot cities' GDP, population, energy consumption and emissions as ratios of those for the whole country.

were about 23,000 Yuan (about 3485 Dollars), were less than half of the national average.

The decrease ratio of the emission intensity is a core indicator of both China's climate policy system and the pilots' targets indices. Fig. 4 shows the decrease rate of emissions intensity in 2010–2014 between the pilot's regions and provinces. In 32 pilots, 24 cities showed faster decreasing speed than their provinces. Although the performance can't be attributed to the pilot policy completely, the policy did certainly contribute. Specially, Jinchang, Urumchi, Qingdao and Great Khingan had shown an astonishing decreasing speed, because rapid development of clean energy and the decrease of energy-intensive industries. For example, the amounts of natural gas consumption had increased by 148% in Urumchi, which possesses rich natural gas resources; the share of renewable energy in total energy consumption had increased to 8.4% in Jinchang, a city with rich wind and solar radiation resources; in the Great Khingan, a small city dominated by forestry, the share of industry in GDP had decreased to 8.8% from 23.7% in 2010–2014; while in Qingdao, an international metropolis, the share of the service sector in GDP had increased to 52.8% from 46.8%.

2.3. Cross-cutting comparative analysis

The 32 cities are very different in terms of population, GDP, emissions and other endowments and features, and tell distinct tales of low-carbon development. In this study, we employ the cross-cutting comparative method to explore their common ground, which can be attributed to the pilot project to a great extent. The progress levels of 32 city pilots are compared in a unified fashion. The comparative contents include: governance systems, goals, carbon emissions statistical system, sectoral practice, and policy and institutional exploration. The primary data is derived from the 32 cities' self-assessment reports. In 2016, the NDRC carried out an official evaluation aimed at the initial two batches of low-carbon pilots. The evaluation was conducted according to the pilot regions' self-assessment reports and face-to-face communications with local responsible officials. The self-assessment reports were written in a unified format and are composed of several blocks: general situations, governance concepts, completion degree of pilot tasks, capability building, mechanism innovations, local experiments, suggestions for pilot projects and appended key data statistics. To ensure the reliability of local self-assessment reports, a series of supporting materials such as local statistical bulletins, government documents and plans were also attached. The official detailed self-assessment reports laid a solid foundation for this study.

What's more, several authors in this study participated in the official evaluation, the face-to-face communications between local responsible officials and experts, which were recorded. Frequent questions included: Had the pilot project had promoted the city's low-carbon transition? What are the barriers to local low-carbon development? How the city aimed to decouple GHG emission from economic growth? Compared to the self-assessment reports, these interviews offered more insightful implications for this study.

3. National requirements and supporting polices for city pilots

3.1. Criteria for candidates

Local government's enthusiasms, their representativeness in economic and social development, and geographical balance are considered as the primary criteria of selecting low-carbon pilots by the NDRC. In detail, the criteria changed greatly with time as the policy was implemented (see Table 1).

Before 2010, when the first batch of low-carbon pilots was established, the concept of being "low-carbon" was very strange for most local officials. At the beginning of China's low-carbon development, the local work foundation was considered the most important factor by the NDRC. As a result, only 5 provinces and 8 cities were listed in the first batch of pilots (see Fig. 1).

In 2011, the State Council released the "12th Five Year Plan on National Economic and Social Development", which had the highest priority among all government plans. It listed low-carbon pilot policy as a key governance measure for controlling GHG emissions. As a

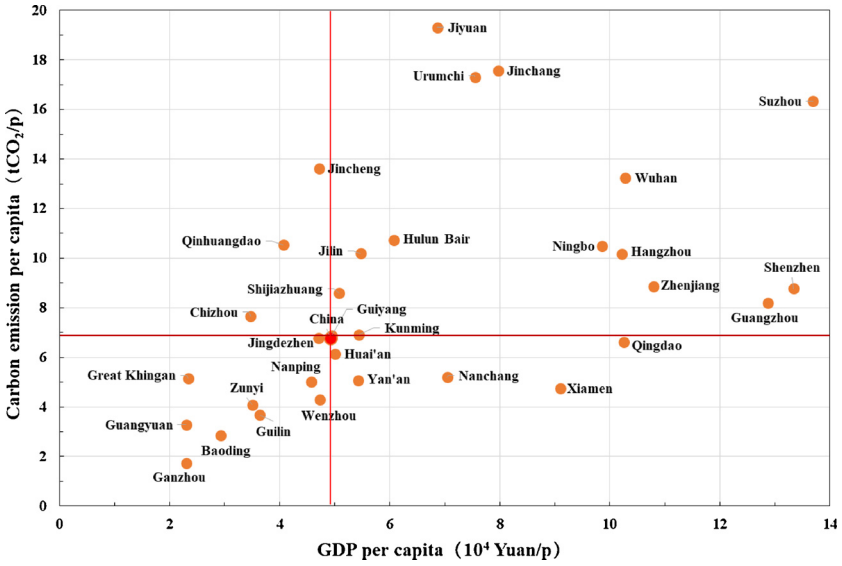

Fig. 3. The pilot cities' distributions in the indices of per capita GDP and emissions in 2014.

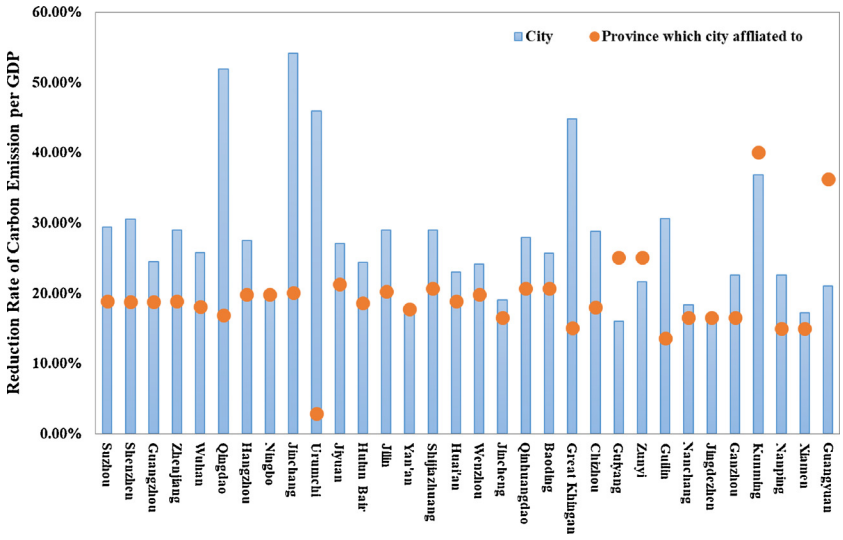

Fig. 4. Comparison of the decrease ratio of emissions intensity in 2010–2014 between pilot's regions and their provinces.

response, the NDRC launched the second batch of pilots in 2012. According to "The notice on applying for the second batch of low-carbon pilots" directive, a candidate city should meet 4 criteria and be recommended by provincial Development and Reform Committees. Considering that low-carbon development is overall and comprehensive, local leaders (e.g., secretary or mayor) are required to play a core role in the low-carbon pilot, which means that they should take all the responsibilities of low-carbon related work. After being appraised by experts, 1 province, 2 provincial-level municipalities and 26 prefecture-level cities were listed in the second batch of low-carbon pilots.

In 2016, for the implementation of the "13th Five Year Plan on National Economic and Social Development" and the "Central City Working Conference", the NDRC released "The notice on applying for the third batch of low-carbon pilots". The candidate cities were explicitly limited to the city-level government, and the provincial-level governments were excluded. Considering that in 2014 China had committed to achieve peak carbon dioxide emissions by around 2030 and make best efforts to peak even earlier, the candidate cities were required to raise explicit targets on emissions peak. Compared to the initial two batches, the third batch of low-carbon pilots involved more cities: 37 prefecture-level cities, 4 county-level cities, 3 counties and 1 district were listed.

3.2. Low-carbon pilot tasks

Policy experimentation is a purposeful and coordinated activity, and it intends to explore novel policy options which can be replicated on a larger scale. The low-carbon pilots had been given several explicit tasks by the central government: for example, they should explore pathways of balancing economic growth and emissions reduction, produce feasible solutions in several key fields and offer insightful experiments and lessons to other regions. However, those tasks changed greatly with the evolution of national climate policies (See Table 1), which reflects the progress of China's low-carbon pilot project.

Table 1
The national requirements for three batches of the low-carbon pilots.

	Numbers	Criteria on Candidates	Tasks
1st batch pilots	5 provinces; 2 provincial-level municipalities 6 prefecture-level cities	Did not appear in official documents	1. Make local low-carbon plans 2. Support low-carbon development by various policies 3. Develop industrial systems characterized by low emissions 4. Build statistics and management system for GHG emissions 5. Initiate low-carbon lifestyle and consumption patterns
2nd batch pilots	1 province; 2 provincial-level municipalities 26 prefecture-level cities	1. Local chief leaders attached great importance to low-carbon development 2. Raised explicit piloting targets, including decreasing the rate of emissions intensity, the share of non-fossil energy in total primary energy, and carbon sinks, etc. 3. Representative in some fields related to low-carbon development 4. Made a preliminary work plan of low-carbon development 5. Received recommendation of provincial government or Develop and Reform Commissions	1. Raise explicit targets and work principles 2. Make local low-carbon plans 3. Develop industrial systems characterized by low emissions 4. Build statistics and management system for GHG emissions 5. Build target responsibility system for emissions control 6. Initiate low-carbon lifestyle and consumption pattern
3rd batch pilots	37 prefecture-level cities 4 county-level cities 3 countries 1 district	1. Local chief leaders attached great importance to low-carbon development 2. Raised explicit targets for emissions peak, the decreasing rate of emissions intensity, total emissions, the share of non-fossil energy in total primary energy, and carbon sinks, etc. 3. Was representative in some fields related to low-carbon development 4. Modest city size	1. Raise explicit targets and work principles 2. Make local low-carbon plans 3. Build target responsibility system for emissions control 4. Explore creative local experiments 5. Enhance comprehensive management ability for low-carbon development

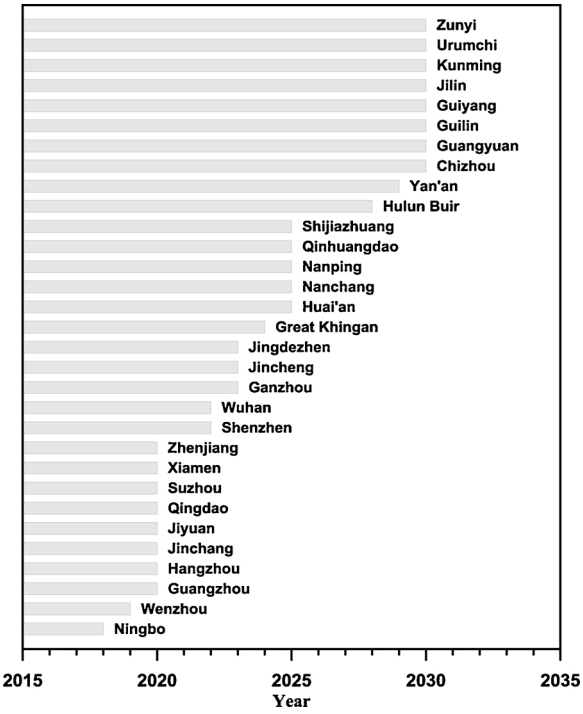

Fig. 5. The targeted peak years for the initial two batches of pilot sites.

At the beginning, the tasks of the first batch pilots included: making low-carbon plans, implementing low-carbon policies, developing low-carbon economics, building CO_2 inventory systems for GHG emissions and leading low-carbon lifestyles. Relatively speaking, the tasks of the first batch of pilots were more general. At that stage, the low-carbon pilots were more or less completely explorative.

When the second batch of pilots was published, the NDRC had obtained several policy experiments from the first batch of pilots. As a result, the NDRC raised several specific requirements, including setting targets on emissions intensity reduction and building a target responsibility system (TRS) for emissions control. It indicated that the NDRC's requirements were increasingly embodied in the low-carbon pilots. When the third batch of pilots was published, the NDRC did not only raise common requirements but also added policy innovations. For example, Hefei's emphasis on policy innovations included a carbon data management system and low-carbon production and technique popularization mechanisms; at the same time Dalian focused on low-carbon production certification, carbon labeling and low-carbon supply chain system innovations. Although the NDRC raised different requirements for different batches of pilots, the latest requirements are applied to all pilots in practice.

3.3. Supporting policies

In order to motivate these city pilots, the NDRC committed several incentive policies. However, these commitments were not explicit in official documents. In practice, these supporting policies included: 1) Offering about 1–3 million Yuan (about 0.15–0.45 million Dollars) in research funds for each project. These funds were endowed by the China Clean Development Mechanism (CDM) Fund, which mainly came from national revenue from CDM projects. The research funds were usually used to compile the local GHG emissions inventories and special plans on low-carbon development. 2) Conducting capability training aimed at city administrators. The scope of capability training included: awareness of addressing climate change, the technologies for compiling GHG emissions inventories and the tactics for low-carbon transition. 3) Promoting international collaboration. For instance, in the past several years, city pilots have attended the Summit of Sino-US Low-Carbon Cities and the Summit of Sino-European Low-Carbon Cities.

4. Local progress

4.1. Governance system

31 pilots have set up their low-carbon development leading groups. In China's specific governance system, the leading group is the superlative coordinate organization. The leading group is led by the mayor, and its members include almost all directors of administrative institutions affiliated with the city government. The goal of the group is to remove the obstacles to low-carbon development. Meanwhile, the leading group is also a decision maker. The group makes final decisions for the city's low-carbon strategy and targets, which are drafted by the local Development and Reform Committee, the actual responsible organ. In practice, the leading group played a key role in making strategies and implementing polices. On the one hand, the cross-sectoral policies and measures can be implemented more harmoniously. On the other hand, the low-carbon policies can be published in the name of the government instead of the local Development and Reform Committee, which promoted the priority level of the low-carbon policies in the city.

Although the officially published criteria and tasks for the second batch of pilots don't claim an emissions peak target, the requirement has been carried out by the NDRC in practice. As a result, all the pilots in the second batch proposed emissions peak targets in their pilot implementing plans. However, these targets weren't released publically until 2014, when China announced its national target of reaching a CO_2 emissions peak by around 2030 or earlier. In the first China-US climate summit in September 2015, 11 provinces and cities including Sichuan, Beijing and Wuhan initiated the Alliance of Peaking Pioneer Cities of China (APPC) and committed their peak targets for the first time publically. Currently, 31 pilots have committed to peaking emissions no later than 2030 in various forms (Fig. 5). Specially, Wuhan and Qingdao institutionalized their peak targets into their highest priority city plans - the 13th Five Year Plans on National Economic and Social Development. It is worth mentioning that these pilots don't state the corresponding peak GHG emissions level, although the amounts have been estimated, which are consistent with those proposed by the central government.

For other targets including the emissions intensity, non-fossil energy and carbon sinks, which are required by the NDRC and were implemented in the National 12th and 13th Five-Year-Plans, all pilots had written them into their own corresponding Five-Year-Plans as binding targets. To meet these targets, all pilots made low-carbon development-specific plans and decomposed those targets and tasks down to corresponding agencies and bureaus.

4.2. Carbon emissions statistical system

A timely and reliable emissions data statistical system plays a fundamental role in policy formulation, implementation, tracking and assessment. Currently, 25 pilots have compiled their GHG emissions inventories (Table 2). Hangzhou, Ningbo and Wenzhou have compiled detailed county-level emissions inventories, while those three cities and Shenzhen and Jinchang have established a normalized inventory compilation mechanism. In order to collect the emissions data in time, seven pilots including Zhenjiang, Wuhan and Qingdao have established an institutionalized online reporting system aimed at key emitters.

Based on the emissions statistics, 12 pilots including Zhenjiang, Wuhan and Suzhou have developed data management platforms. For example, Zhenjiang's platform has four key functions, namely assessing the carbon impacts of new industrial projects, examining their low-carbon performances, outlining a feasible roadmap for achieving emissions peak, and monitoring and providing forewarnings to key enterprises on their emissions.

Table 2
The progress of carbon emissions statistics system for the 32 national pilots.

	JCS	JCG	SZG	NC	JY	YA	GZG	WH	BD	ZJ	HZ	SJZ	UR	HB	JL	QD	WZ	NB	GYG	QHD	SZJ	GZJ	KM	GL	GYS	NP	HA	CZ	GK	JDZ	XM	ZY
GHG emissions inventory		■	■	■		■		■	■	■	■	■	■		■	■	■	■		■	■		■	■	■	■	■	■		■	■	■
Carbon data management platform	■	■				■	■	■		■	■	■					■	■								■							
Statistical platform of key enterprises	■						■	■		■	■					■			■														

Notes: JCS: Jincheng; JCG: Jinchang; SZG:Shenzhen; NC: Nanchang; JY: Jiyuan; YA: Yan'an; GZG: Guangzhou; WH: Wuhan; BD: Baoding; ZJ: Zhenjiang; HZ: Hangzhou; SJZ: Shijiazhuang; UR: Urumchi; HB: Hulun Bair; JL: Jilin; QD: Qingdao; WZ: Wenzhou; NB: Ningbo; GYG: Guiyang; QHD: Qinhuangdao; SZJ: Suzhou; GZJ: Ganzhou; KM: Kunming; GL: Guilin; GYS: Guangyuan; NP: Nanping; HA: Huai'an; CZ: Chizhou; GK: Great Khingan; JDZ: Jingdezhen; XM: Xiamen; ZY: Zunyi.

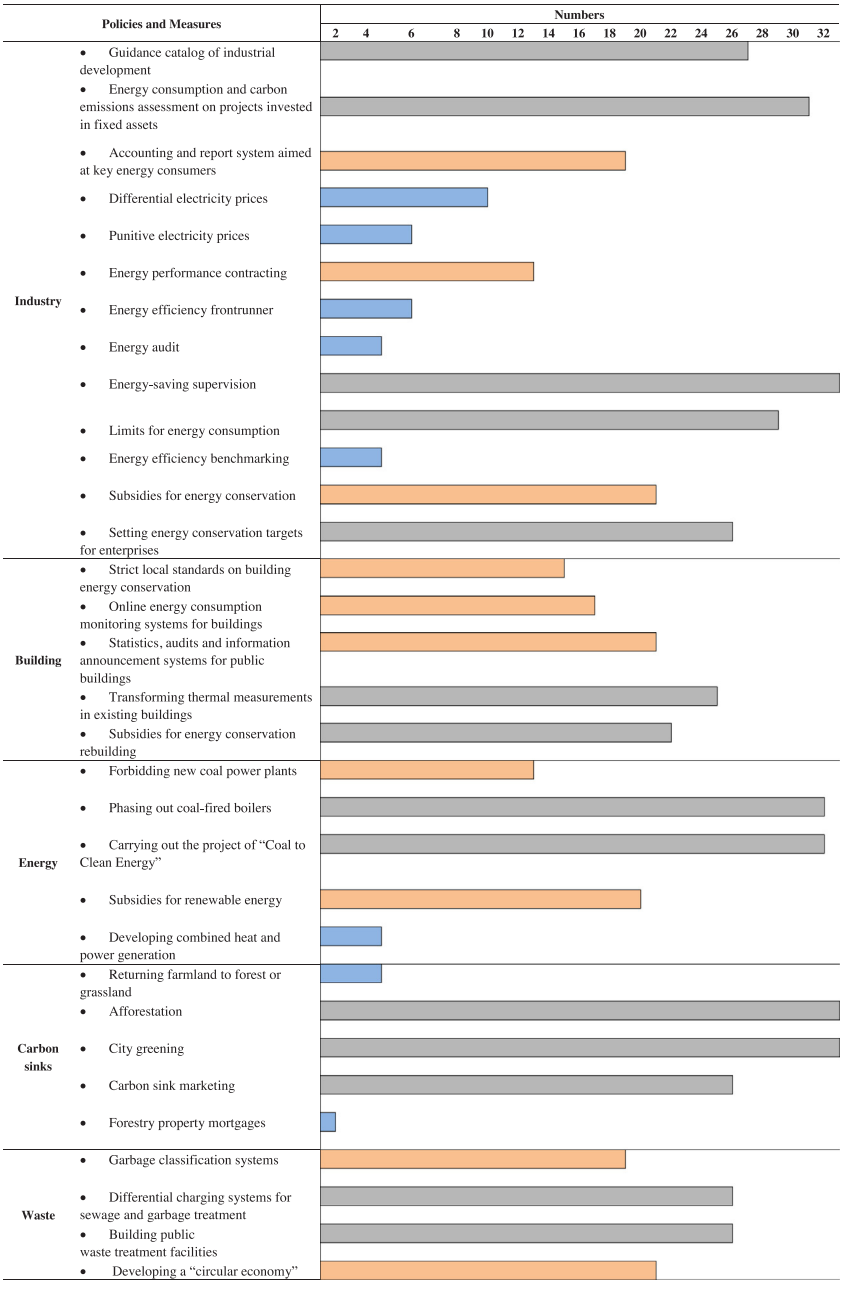
Policies and Measures
Numbers
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Industry
• Guidance catalog of industrial development
• Energy consumption and carbon emissions assessment on projects invested in fixed assets
• Accounting and report system aimed at key energy consumers
• Differential electricity prices
• Punitive electricity prices
• Energy performance contracting
• Energy efficiency frontrunner
• Energy audit
• Energy-saving supervision
• Limits for energy consumption
• Energy efficiency benchmarking
• Subsidies for energy conservation
• Setting energy conservation targets for enterprises
Building
• Strict local standards on building energy conservation
• Online energy consumption monitoring systems for buildings
• Statistics, audits and information announcement systems for public buildings
• Transforming thermal measurements in existing buildings
• Subsidies for energy conservation rebuilding
Energy
• Forbidding new coal power plants
• Phasing out coal-fired boilers
• Carrying out the project of "Coal to Clean Energy"
• Subsidies for renewable energy
• Developing combined heat and power generation
Carbon sinks
• Returning farmland to forest or grassland
• Afforestation
• City greening
• Carbon sink marketing
• Forestry property mortgages
Waste
• Garbage classification systems
• Differential charging systems for sewage and garbage treatment
• Building public waste treatment facilities
• Developing a "circular economy"

Fig. 6. Frequently-used policies and measures of different sectors in 32 pilots.

4.3. Sectoral policies

Sectoral policies are the primary means of local low-carbon development. Currently, all pilots had taken various actions with respect to the industrial system, building, transportation, energy, carbon sinks and waste management. Fig. 6 lists the most frequent policies and measures to summarize sectoral policies.

4.3.1. Industries

Developing an industrial system characterized by low emissions is the most important task of low-carbon pilots. With the goal of decreasing emissions intensity, the actions can be divided into 2 categories: adjusting the industrial structure and adopting low-carbon technologies. The structural pathway includes: restraining the rapid growth of energy intensive industries, eliminating backward production capacities, and expanding the share of low-carbon industries. In practice, sectors such as tourism, logistics, agriculture, e-commerce and finance are the most commonly targeted low-carbon industries. The technological pathway puts emphasis on the key energy consuming industries. These pilots employed command-and-control, incentive and market-based tools to motivate energy conservation. Frequently-used policies include: publishing guidance catalogs of industrial development, conducting energy consumption and carbon emissions assessment on projects invested in fixed assets, setting energy conservation targets for key enterprises and implementing target responsibility management, enforcing stricter limits on energy efficiency, and giving subsidies for energy conservation.

The development of low-carbon industry usually reflects a city's transformation. Take Guangzhou as an example, which has implemented various policies to reduce industrial emissions, including: (1) set up 2 billion Yuan (about 303 million Dollars) in specific funds each year to cultivate emerging and strategic industries; (2) set up a joint meeting office to facilitate the elimination of backward production capacity. In 2010–2014, 314 high-energy consumption and high pollution industrial enterprises were closed, and more than 600 industrial enterprises were encouraged to carry out energy efficiency technology improvement.

4.3.2. Buildings

The core measures for decreasing emissions in buildings can be summarized into 4 categories: enforcing stricter design standards for energy efficiency of new buildings, rebuilding existing buildings, popularizing renewable energy and developing green buildings. Several pilots including Hangzhou, Shenzhen, Kunming and Guiyang have released corresponding local guidelines entitled, "Regulations on Energy Conservation Management in Building", which ensured the enforcement of stricter standards. In addition, most pilots carried out energy-saving reconstruction in existing buildings, especially in public buildings such as government institutions, schools and hospitals. For strengthening energy conservation, nearly half of the pilots set up an online energy monitoring platform and information announcement system for public buildings.

4.3.3. Transportation

The transportation contents of low-carbon pilots are highly coupled with the other demonstration projects, such as "Demonstration of New Energy Vehicle Promotion and Application", "Demonstration of Urban Public Transport Construction", and "Demonstration of Urban Walking and Bicycle Transport System". Local actions related to low-carbon transportation can be summarized into 5 aspects: expanding public transportation by building bus rapid transit and rail transit; restraining private vehicle traffic based on tail number; encouraging non-motorized traffic by building public bicycle rental networks; popularizing new energy vehicles through fiscal subsidies; and developing "smart" transportation systems.

For example, Hangzhou established an integrated green public transportation system consisting of public bicycles, electric taxis, low-carbon buses, water buses and subways. The city has 1600 pure electric buses, 560 taxis, 3500 CNG (compressed natural gas) vehicles and 2400 LNG buses. It has the largest public bicycle system, with more than 3000 service points and 80,000 public bicycles. It has set up a mechanism for sharing the service of the pure electric vehicles, and constructed nearly 100 micro-bus stations, covering the major areas of the city. The traffic system also boasts an extensive subway system, whose total length is about 83 km.

4.3.4. Energy

To build a low-carbon energy system, most cities put emphasis on reducing coal consumption by putting forward explicit targets. Popular policies include: forbidding new coal power plants, phasing out coal-fired boilers, restricting the usage of bulk coal, and carrying out the national project of transforming "Coal to Clean Energy". To accelerate the substitution of coal, more and more pilots accelerated the construction of natural gas pipelines and designated natural gas as leading future energy source. In addition, almost all pilots released incentive policies to stimulate the usage of renewable energy.

4.3.5. Carbon sinks

Most pilots have taken the task of increasing carbon sinks as an important policy and issued specific plans and measures. The most widely used measures include: returning farmland to forest or grassland, afforestation, forest management and nature conservation. In addition, some innovative practices have been carried out. For instance, Wenzhou proposed to build a demonstration plot of fishery carbon sequestration; Guangzhou complied the first city-level map of forest carbon sinks; and Hulun Bair carried out a systematic investigation of the carbon sinks of its forests, grasslands and wetlands.

4.3.6. Waste management

Waste management has received significant attention in recent years with the tremendous growth in domestic garbage. Pilots have focused on developing waste management systems that consider the life-cycle periods of products, and the processes related to creating landfills, garbage incineration, and garbage reduction. Waste classification systems have been implemented for several years in a number of pilots, but the effectiveness has not been obvious. More specifically, Guilin and Xiamen controlled landfill methane and used the biogas to generate power; Zunyi implemented a unified recycling and disposal system for waste oil; while Wenzhou used discarded edible oil to make biodiesel.

4.4. Policy and institutional explorations

Institutions are the humanly devised schemes, norms, and regulations that regulate the relations and interactions between individuals, groups and organizations (Hargrave & Ven, 2006; Scott, 2001). By reshaping the behaviors of stakeholders, institutional innovation plays a central role in policy experiments. Since 2010, the pilots have conducted a large number of institutional explorations and afforded abundant local experiments, which were then scaled-up and applied to the whole country. The key institutional innovations included: carbon legislation, target responsibility system, total coal and emissions amount control, carbon assessment, carbon trade, carbon neutrality, carbon certification, carbon benefiting, special funds and green credit (Shown in Table 3).

4.4.1. Legislation

Legislations are the highest forms of institutional innovation, which solidify the responsibilities of stakeholders and clarify their interactions. Three pilots including Shijiazhuang, Nanchang and Jincheng made local laws to promote low-carbon development, which provided important references for the ongoing national "Chinese Law on Climate

Table 3
The policy and institution explorations for the 32 national pilots.

	JCS	JCG	SZG	NC	JY	YA	GZG	WH	BD	ZJ	HZ	SJZ	UR	HB	JL	QD	WZ	NB	GYG	QHD	SZJ	GZJ	KM	GL	GYS	NP	HA	CZ	GK	JDZ	XM	ZY
Emissions per capita in 2014 (tCO_2/p)	13.63	17.57	8.78	5.20	19.31	5.08	8.18	13.23	2.87	8.86	10.18	8.59	17.30	10.74	10.19	6.63	4.29	10.49	6.90	10.53	16.34	1.74	6.91	3.68	3.29	5.01	6.15	7.66	5.16	6.79	4.76	4.09
Emission intensity in 2014 (tCO_2/10,000 Yuan GDP)	2.89	2.21	0.66	0.74	2.81	0.94	0.64	1.29	0.98	0.82	1.00	1.69	2.29	1.77	1.86	0.65	0.91	1.06	1.39	2.59	1.19	0.75	1.27	1.01	1.43	1.10	1.23	2.21	2.21	1.44	0.52	1.17
Reduction rate of emission intensity in 2010-2014 (%)	19.01	54.17	30.53	18.37	27.10	17.00	24.50	25.80	25.66	29.01	27.54	29.00	45.95	24.40	29.00	51.85	24.17	20.03	16.04	27.93	29.41	22.61	36.85	30.64	21.03	22.58	23.00	28.80	44.80	17.02	17.18	21.65
Carbon legislation	■			■								■																				
Target responsibility system	■		■	■	■	■		■	■	■	■	■			■	■		■		■	■	■	■		■	■	■	■		■	■	■
Total amount control		■		■	■					■		■			■							■	■									
Carbon assessment	■						■			■																						
Carbon trade		■	■	■	■	■	■	■						■	■	■			■	■	■	■					■				■	
Carbon neutrality	■	■	■		■		■			■				■			■			■					■	■		■	■			
Carbon certification	■		■	■		■		■								■	■	■						■			■					
Carbon benefiting						■																										
Special funds	■	■	■	■		■	■	■		■	■	■	■			■	■	■	■		■	■	■	■		■	■			■	■	
Green credit															■			■						■		■						

Notes: JCS: Jincheng; JCG: Jinchang; SZG:Shenzhen; NC: Nanchang; JY: Jiyuan; YA: Yan'an; GZG: Guangzhou; WH: Wuhan; BD: Baoding; ZJ: Zhenjiang; HZ: Hangzhou; SJZ: Shijiazhuang; UR: Urumchi; HB: Hulun Bair; JL: Jilin; QD: Qingdao; WZ: Wenzhou; NB: Ningbo; GYG: Guiyang; QHD: Qinhuangdao; SZJ: Suzhou; GZJ: Ganzhou; KM: Kunming; GL: Guilin; GYS: Guangyuan; NP: Nanping; HA: Huai'an; CZ: Chizhou; GK: Great Khingan; JDZ: Jingdezhen; XM: Xiamen; ZY: Zunyi.

Change". The first local low-carbon legislation, called "the Shijiazhuang Low-Carbon Development Promotion Ordinance", has been approved by the Hebei Provincial People's Congress. All governments above the county level should promote local low-carbon development by making and implementing relevant policies; enterprises should apply low-carbon technologies to decrease emissions; while society at large is encouraged to have increased low-carbon awareness and conduct low-carbon consumption.

4.4.2. Command mandatory institutions

Current institutional explorations focus on the interaction between governments and enterprises. There are eight pilots, including Jiyuan, Kunming and Jilin, that explored a total emissions amount control system. In the system, governments at higher levels decompose the total emissions target down to subordinate governments and key enterprises. Meanwhile, the government employs the target responsibility system to evaluate policy effectiveness. For those that failed to meet their targets, their leaders were not awarded any annual rewards or honorary titles, resulting in setbacks in their careers. Furthermore, the city's new investment projects were suspended.

4.4.3. Informative institutions

In order to control the rapid increase of carbon emissions, 3 pilots including Wuhan, Zhenjiang and Jincheng employed the carbon assessment system to review new investment projects. In the system, carbon emissions limits were considered a necessary standard for new projects, and those that fell short were rejected. In practice, local governments usually conducted carbon assessments combined with energy and environmental assessments. Pilots, namely Qingdao, Shenzhen, Ningbo, Wenzhou, Wuhan and Huai'an, had developed carbon certification systems to promote the application of low-carbon technologies and low-carbon products. Currently, the scope of carbon certification covers the glass, cement, building material and motor sectors.

4.4.4. Incentive institutions

There were 20 pilots that set low-carbon development specific funds or integrated related funds for energy saving and emissions reduction, new energy development funds and environmental protection. In 2012–2015, Shenzhen arranged for 0.96 billion Yuan (about 146 million Dollars) to support circular economy, energy saving and emissions reduction; 2.2 billion Yuan (about 333 million Dollars) to accelerate the new energy industry; and 1 billion Yuan (about 152 million Dollars) to support the development of industries related to energy saving, advanced environmental protection and resource recycling. In total, 4 pilots explored green credit to support enterprises' energy saving and emissions reduction. For example, the Jilin city government and Jilin Bank signed a cooperation agreement to promote energy conservation and emissions reduction demonstration projects. According to the agreement, Jilin Bank will provide 20 billion Yuan (about 3030 million Dollars) of credit allowance with low interest rates.

4.4.5. Market institutions

As pilot sites for the national carbon trading scheme, Shenzhen, Guangzhou and Wuhan had done foundational work in carbon emissions measurement, monitoring and verification, and have begun trading CO_2 according to the "Notice on Carbon Trading Pilots" announced by the NDRC in 2011. Beyond that, 11 low-carbon pilots also participated in the carbon trading system. For example, Jinchang published "Implementation Scheme on Establishing Carbon Emissions Trading Market", "Implementation Regulations on Carbon Emissions Trade" and "Schemes for Carbon Emissions Cap Setting and Quota Allocation". Jinchang has already achieved third-party verification and provided quota allocations to 24 key emitters.

4.4.6. Voluntary institutions

Guangyuan, Jincheng, Suzhou and 11 other pilots carried out carbon neutrality projects. For example, Guangyuan and the Shanghai World Expo collaborated to carry out carbon neutrality projects aimed at advancing low-carbon transportation in 2010. The project sold 36 thousand tons of carbon emissions. Suzhou established a carbon neutrality platform, which provided a way for enterprises to trade. Guangzhou established an initiative to promote low-carbon consumption in which participants obtained credits for low-carbon behaviors such as taking public transport and saving water and electricity.

5. Discussion

5.1. Comparison with international low-carbon city networks

There are some common features among the existing low-carbon city networks, including C40, the Covenant of Mayors and China's Low-Carbon City Pilots. Firstly, the starting point of these networks is translating national climate targets into cities' actions. Their

memberships must set explicit GHG emissions reduction targets and strive to reach them by implementing policies and measures. Secondly, these networks can be seen as a coordinated collection of experiments based on some specific rules. Local best practices in implementing climate policies can be disseminated through these networks, which will help more cities reduce their GHG emissions in more suitable ways (Bulkeley & Broto, 2013). Thirdly, these networks can be seen as a voluntary policy tool. Although the networks promise assistance in technology or funding, the low-carbon actions should be conducted consciously by the cities themselves.

In details, these networks are very different in the implementation process. Briefly, China's low-carbon city pilots place emphasis on "entry". A city that wants to join in the project must meet several criteria, while the specific technology guidelines and evaluation systems are very vague. In contrast, the Covenant of Mayors is open to any city willing to commit to a CO_2 reduction target of 20% minimum, but the city must follow standardized guidelines and methodologies in designing and implementing policies and measures to reach them (The Covenant of Mayors, 2018). The Covenant of Mayors offers two detailed guidelines: Baseline Emissions Inventory (BEI) and Sustainable Energy Action Plan (SEAP). The BEI is a quantification of the amount of CO_2 emissions within a given period of time. It is used to identify the primary emissions sources and to analyze the city's emissions reduction potential. The SEAP is the key document that defines the activities and measures set up to achieve the target (Bertoldi, Bornás Cayuela, Monni, & Raveschoot, 2010). The elaborated guidelines create a homogeneous database of plans and actions suitable for observation and comparison, which is very helpful in monitoring, collecting, evaluating, and diffusing the local experiments (Croci, Lucchitta, Janssens-Maenhout, Martelli, & Molteni, 2017).

5.2. The deficiencies of China's low-carbon city pilots

As an explorative policy experiment, China's low-carbon pilots made a key step towards low-carbon development. Focusing on how to develop a low-carbon city, the majority of pilots had compiled their GHG emission inventories, set explicit targets of emissions reduction and carried out low-carbon actions. Meanwhile, a governance system "with Chinese characteristics" had been established: setting up a low-carbon development leading group led by the local head official and employing the target responsibility system to ensure the achievement of the target for emissions intensity reduction. In addition, various innovative policies and institutions including carbon legislation, carbon assessment, carbon trade, carbon neutrality, and carbon certification had been explored, which provided important policy options for nationwide low-carbon development. Despite the positive progress, there remain some deficiencies in China's low-carbon city pilots, which have hindered the formation and diffusion of local experiments.

5.2.1. The conundrum of transforming development patterns

In recent years, owing to slower economic growth rates and an extraordinary decrease in energy intensive industries, the carbon emissions of many pilots have been stable or even reduced slightly. Political emphasis on "Green Development" and the "New Normal" diminished local governments' focus on economic expansion. However, it still failed to fundamentally change the local governments' preferences for certain development patterns. For example, Wuhan is attempting to double its GDP to 2000 billion Yuan by 2021, and Zunyi set a 13% target of annual economic growth during the 13th Five Year Plan.

The slowdown of economic growth plays a key role in reducing emissions, but it causes the dwindling of fiscal revenues, which challenges local governments. Most low-carbon pilots have to struggle between expansion-based development and low-carbon development, and they cannot easily find suitable low-carbon development patterns or pathways, or change traditional development patterns. Except for a small number of developed regions, a large number of pilot cities have not yet achieved structural improvements of their economy as they face difficulties in attracting advanced industries and innovative policy designs for sustainable development. Although low-carbon pilots have incentives to support low-carbon development, they often find themselves in regional competition and thus grant top priority to GDP growth, and a much lower priority to low-carbon development. Limited by institutional factors and capacities, the vast majority of low-carbon pilots are painfully conflicted between expansion-based development and low-carbon development. Balancing economic growth and emissions reduction remains a major conundrum for local governments.

5.2.2. The gap between views and actions

Although most pilots have proposed ambitious targets such as achieving earlier emissions peaks, decreasing emissions intensity and increasing the share of non-fossil fuels, and formulated special low-carbon development plans, the corresponding roadmaps and implementation mechanisms still often fall short of targets. Low-carbon development is a comprehensive social and economic reform rather than a simple, specific task. The current low-carbon plans are meaningful but are difficult to apply and put into practice.

Technically, there is a huge gap between the low-carbon targets and practical measures. Currently, the low-carbon pilots usually are responsible to the local Development and Reform Committees, while most tasks are in the remit of other departments or bureaus. For instance, low-carbon transportation is in the charge of the Bureau of Transportation, low-carbon building is in the charge of the Bureau of Housing and Urban-Rural Development, and low-carbon industry usually is in the charge of the Bureau of Industry and Information Technology. As a result, low-carbon plans are usually assembled from various related plans. The cross relations among different departments or bureaus are difficult to coordinate. In the process of policy implementation, low-carbon plans are far lower in priority than the statutory and mandatory plans such as urban development planning and urban land utilization planning, as well more sector-specific plans, such as the industrial plans, transportation plans and building plans. These plans are composed of a series of construction projects, and serve the cities' economic and livelihood goals. In China's city governance, these projects usually are listed as local priority work. Although the cities strive to pursue a coordinated way forward between the economic goals and low-carbon goals, they prefer the former in practice, especially for those cities that are still on the lower end of the development spectrum. As a result, several indicators in the low-carbon plans changed in the opposite direction. For examples, in 2010–2014, the share of the industrial sector in the GDP had raised to 44.8% from 41.8% in Zunyi, 39.0% to 47.2% in Guangyuan, and 41.9% to 43.2% in Nanping, which are inconsistent with their low-carbon goals but guarantee their economic goals.

5.2.3. Weak support from the central government

The support of the central government is vital to the success of low-carbon pilots, as low-carbon cities remain a kind of voluntary policy tool. The support includes special policies, direct financial funds and detailed technical guidelines, which have played a core role in China's policy experiments more generally (Heilmann, 2008). For example, the central government authorized for the Xiong'an New Area special financial and land polices to explore a new urban planning model. In the "sponge city" pilots aimed at reducing urban water logging, the central government gave 0.5 billion Yuan (about 76 million Dollars) fiscal support to each pilot. Compared to these pilots, the NDRC's support for low-carbon pilots remains insufficient. Compared to the Covenant of Mayors, the technical guidelines of the NDRC are also vague. According to the cities' self-assessment reports, the majority of city pilots expected to obtain special finance and taxation polices and receive detailed technical guidelines in formulating emissions reduction plans. Due to the weak support, the low-carbon pilots have found it very difficult to comply with national low-carbon policies completely.

6. Conclusion and policy recommendations

Based on the official self-assessment reports, this paper investigates the progress of 32 prefectural low-carbon city pilots in the initial two batches of this policy. As a policy experiment, the low-carbon pilots have made progress and provided an important reference for other cities of the country. Their achievements can be summarized into four aspects. Firstly, a comprehensive governance system led by the local head official and involving a majority of governmental agencies was established, which played a core role in raising peak emissions targets, making low-carbon strategies and plans, and implementing low-carbon polices. Secondly, carbon emissions statistical systems were established, which laid foundations for policy formulation, implementation, tracking and assessment. Thirdly, low-carbon actions covering a majority of emissions sectors were carried out, which produced positive consequences for local low-carbon development. Lastly, many new policies and institutions including legislation, emissions control, carbon certification and green credit were explored. The progress provided an important foundation for the formulation of nationwide policy.

However, despite this positive progress, it is still difficult to diffuse the local experiments nationwide. On the one hand, local experiments haven't been assessed systematically, and effective policies and measures haven't been identified scientifically. On the other hand, there are still several institutional weaknesses in the process of implementing pilot policy, which obstruct the further exploration of low-carbon pilots. We therefore provide some policy recommendations.

Firstly, the central government should support local low-carbon development by integrating various polices. Historically, policy experimentation within the governance hierarchy has played an important role in China's economic rise. However, many experimental programs aiming to provide an effective provisioning of social goods failed due to the lack of active societal supervision and constricted the central government's enforcement capacity (Heilmann, 2008). Fortunately, China's low-carbon experimentation seems to provide an opportunity for success. On the one hand, China has been putting more and more emphasis on green development and implementing the reforms of "ecological civilization" in recent years. The central government has greatly strengthened enforcement of low-carbon development. On the other hand, societal supervision has also developed gradually. Citizens are becoming more and more concerned about the environment and the country's environmental governance structure has changed in response. The NDRC should take advantage of these opportunities and employ special policies to promote the pilot policy. The NDRC should employ an appraisal system for environmental protection suggested by the central government to conduct stricter target examinations for the pilots. Additionally, the NDRC should integrate various fiscal funds such as the special funding of energy saving and emissions reduction, the renewable energy development fund and air pollution control fund to support the low-carbon pilots.

Secondly, the central government should establish a detailed guideline and a policy assessment system. Since 2010, China has set explicit carbon intensity reduction targets in the 12^{th} and 13^{th} Five-Year Plans. To meet national targets, the central government disaggregated them down to provincial, municipal, county and even township levels of government, as well as to the industrial, agricultural, transportation and building sectors. At the same time, various low-carbon policy instruments were implemented across the whole country, ranging from administrative instruments such as the target responsibility system and initiatives to phase out obsolete industrial capacity, to incentive instruments such as career awards and administrative subsidies for energy savings and various market instruments. Inevitably, there have been significant overlaps between national requirements and low-carbon pilots' autonomous actions. To explore the additionality of pilot policy and to identify effective local experiments, establishing a policy assessment system is necessary. In addition, for policy innovation at the local level, policy assessments should focus on several important issues, for example, effectiveness and efficiency along with fairness and unexpected consequences.

Finally, the central government should summarize and share best practices. Pilot policy is a typical learning-by-doing mechanism. The sources of learning include three primary categories: previous experiences, local practice and expert knowledge. In the process of collective learning, the NDRC should act as the organizer and coordinator. The experiences of experiments scattered across different cities should be summarized through best practices, which help local governments fill the gap between views and actions, and allow the central government to advance the pilot policy further.

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References

Baeumler, A., Ijjaszvasquez, E., Mehndiratta, S., Baeumler, A., Ijjaszvasquez, E., & Mehndiratta, S. (2012). *Sustainable low-carbon city development in China.* World Bank.

Bertoldi, Paolo, Bornás Cayuela, Damian, Monni, Suvi, & Raveschoot, R. P. D. (2010). *How to develop a sustainable energy action plan (SEAP).* EU publications.

Bi, J., Zhang, R., Wang, H., Liu, M., & Wu, Y. (2011). The benchmarks of carbon emissions and policy implications for China's cities: Case of Nanjing. *Energy Policy, 39*, 4785–4794.

Bulkeley, H., & Broto, V. C. (2013). Government by experiment? Global cities and the governing of climate change. *Transactions of the Institute of British Geographers, 38*, 361–375.

C40 (2018). *ABOUT C40, Vol. 2018*. Accessed 30 June 2018 https://www.c40.org/about.

Cai, B., Geng, Y., Yang, W., Yan, P., Chen, Q., Li, D., & Cao, L. (2017). How scholars and the public perceive a "low carbon city" in China. *Journal of Cleaner Production, 149*, 502–510.

Cheng, J., Zeng, G., & Fang, T. (2012). *The origin and connotation of low carbon city: A conceptual framework. In International Joint Conference on Computational Sciences & Optimization*706–709.

Cheshmehzangi, A., Xie, L., & Tan-Mullins, M. (2018). The role of international actors in low-carbon transitions of Shenzhen's International Low Carbon City in China. *Cities, 74*, 64–74.

Chong, W. H. B., Guan, D., & Guthrie, P. (2012). Comparative analysis of carbonization drivers in China's megacities. *Journal of Industrial Ecology, 16*, 564–575.

Croci, E., Lucchitta, B., Janssens-Maenhout, G., Martelli, S., & Molteni, T. (2017). Urban CO2 mitigation strategies under the Covenant of Mayors: An assessment of 124 European cities. *Journal of Cleaner Production, 169*, 161–177.

Fang, C., Wang, S., & Li, G. (2015). Changing urban forms and carbon dioxide emissions in China: A case study of 30 provincial capital cities. *Applied Energy, 158*, 519–531.

Fry, J., Lenzen, M., Jin, Y., Wakiyama, T., Baynes, T., Wiedmann, T., ... Schandl, H. (2018). Assessing carbon footprints of cities under limited information. *Journal of Cleaner Production, 176*, 1254–1270.

Hargrave, T. J., & Ven, A. H. V. D. (2006). A collective action model of institutional innovation. *The Academy of Management Review, 31*, 864–888.

Heilmann, S. (2008). Policy experimentation in China's economic rise. *Studies in Comparative International Development, 43*, 1–26.

Hu, C. (2017). Research on the strategy of low-carbon urban planning based on residents' living and consumption. *IOP Conference Series: Earth and Environmental Science, 61*, 012049.

IEA (2014). *CO2 emissions from fuel combustion (2014).* Paris: IEA.

Lee, C. M., & Erickson, P. (2017). How does local economic development in cities affect global GHG emissions? *Sustainable Cities and Society, 35*, 626–636.

Lin, J., Jacoby, J., Cui, S., Liu, Y., & Lin, T. (2014). A model for developing a target integrated low carbon city indicator system: The case of Xiamen. *China. Ecological Indicators, 40*, 51–57.

Liu, W., & Qin, B. (2016). Low-carbon city initiatives in China: A review from the policy paradigm perspective. *Cities, 51*, 131–138.

Moriarty, P., & Wang, S. J. (2014). Low-carbon cities: Lifestyle changes are necessary. *Energy Procedia, 61*, 2289–2292.

Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2007). China's growing CO2 EmissionsA race between increasing consumption and efficiency gains. *Environmental Science & Technology, 41*, 5939–5944.

Qi, Y. (2013). *Annual review of low-carbon development in China (2013).* Beijing: Social Sciences Academic Press (China).

Qi, Y. (2017). *Annual review of low-carbon development in China (2017).* Beijing: Social Sciences Academic Press (China).

Scott, W. R. (2001). *Institutions and organizations.* Sage Publications.

Su, M., Zheng, Y., Yin, X., Zhang, M., Wei, X., Chang, X., ... Qin, Y. (2016). Practice of low-carbon city in China: The status quo and prospect. *Energy Procedia, 88*, 44–51.

Sugar, L., Kennedy, C., & Leman, E. (2012). Greenhouse gas emissions from chinese cities.

Journal of Industrial Ecology, 16, 552–563.
Tan, S., Yang, J., & Yan, J. (2015). Development of the low-carbon city Indicator (LCCI) framework. *Energy Procedia, 75*, 2516–2522.
Tan, S., Yang, J., Yan, J., Lee, C., Hashim, H., & Chen, B. (2017). A holistic low carbon city indicator framework for sustainable development. *Applied Energy, 185*, 1919–1930.
Tao, Z. (2011). Strategy of city development in low-carbon economic mode-A case study on Qingdao. *Energy Procedia, 5*, 926–932.
The Chinese Society for Urban Studies (2013). *Annual Report on China's Low-carbon and ecological cities 2013*Beijing: China Building Industry Press.
The Covenant of Mayors (2018). *Covenant initiative in figures.* Accessed 30 June 2018 https://www.covenantofmayors.eu/about.
UNFCCC (2015). *'The Paris Agreement', The Conference of the Partie, 2018*. Accessed 15 May 2018 https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.
Wang, N., & Chang, Y.-C. (2014). The evolution of low-carbon development strategies in China. *Energy, 68*, 61–70.
Wang, X., & Chi, C. (2016). Global city indicators: Towards a holistic view of low carbon city dimensions. *Energy Procedia, 88*, 168–175.
Wang, S., & Liu, X. (2017). China's city-level energy-related CO 2 emissions: Spatiotemporal patterns and driving forces. *Applied Energy, 200*, 204–214.
Wang, C., Engels, A., & Wang, Z. (2018). Overview of research on China's transition to low-carbon development: The role of cities, technologies, industries and the energy system. *Renewable and Sustainable Energy Reviews, 81*, 1350–1364.
Wang, H., Wang, Y., Wang, H., Liu, M., Zhang, Y., Zhang, R., ... Bi, J. (2014). Mitigating greenhouse gas emissions from China's cities: Case study of Suzhou. *Energy Policy, 68*, 482–489.
Wang, Y., Song, Q., He, J., & Qi, Y. (2015). Developing low-carbon cities through pilots. *Climate Policy, 15*, S81–S103.
Williams, J. (2016). Can low carbon city experiments transform the development regime? *Futures, 77*, 80–96.
Yang, L., & Li, Y. (2013). Low-carbon city in China. *Sustainable Cities and Society, 9*, 62–66.
Zhang, L., Feng, Y., & Chen, B. (2011). Alternative scenarios for the development of a low-carbon city: A case study of Beijing, China. *Energies, 4*, 2295–2310.
Zhou, N., He, G., Williams, C., & Fridley, D. (2015). ELITE cities: A low-carbon eco-city evaluation tool for China. *Ecological Indicators, 48*, 448–456.